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INTEGRATED ANALYSIS AND APPLICATIONS

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ABSTRACT

A select overview is provided of ongoing research efforts which, in the broadest sense, are all focused toward the development and verification of integrated structural analysis and optimal design capabilities for advanced aerospace propulsion and power systems. The overview incorporates a variety of subject areas including:

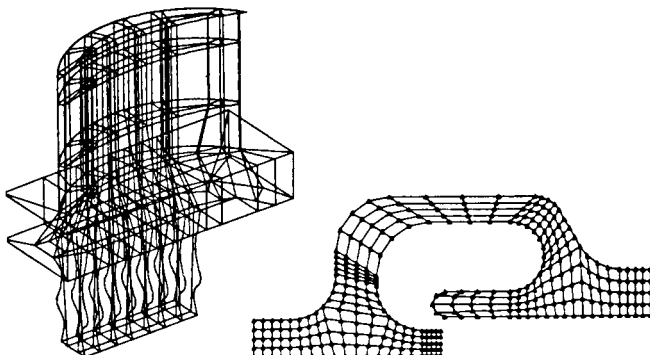
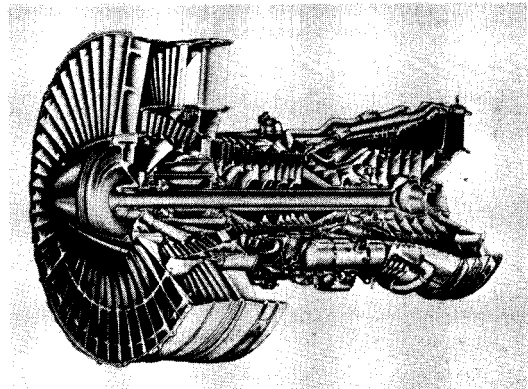
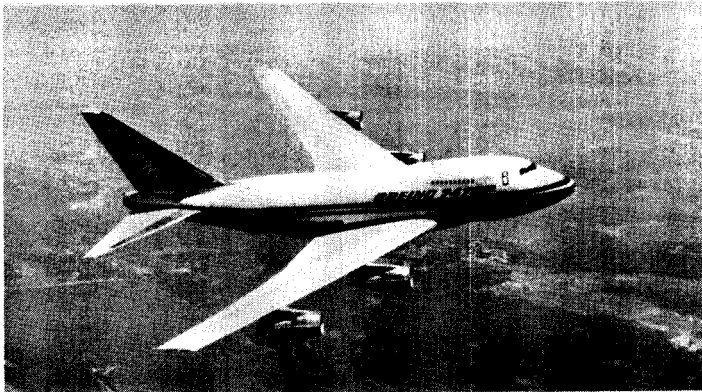
- (1) Composites - analytical models (composite mechanics), integrated computational methods, and experimental characterization of composite structural response and durability for resin-, metal-, and ceramic-matrix systems
- (2) Advanced inelastic analysis - algorithms/numerical methods for more accurate and efficient analysis
- (3) Constitutive modelling - theoretical formulation and experimental characterization of thermoviscoplastic material behavior
- (4) Computational simulation - engine structures from components to assemblies and up to an entire engine system subjected to simulated test-stand and mission load histories
- (5) Probabilistic structural analysis - quantification of the effects of uncertainty in geometry, material, loads, and boundary conditions on structural response for true reliability assessment
- (6) Interdisciplinary optimization - incorporation of mathematical optimization and multidisciplinary analyses to provide streamlined, autonomous optimal design systems

Specific examples are presented which illustrate the utility of these advanced technologies for real-world applications.

3-D INELASTIC STRUCTURAL ANALYSIS METHODS

The desire for increased performance/efficiency of gas turbine engines has led to designs having more severe operating cycles - i.e., higher pressures and temperatures. The general result has been an exhibited decrease in engine durability with an associated increase in maintenance costs, particularly in the hot section where more hostile environments accelerate component wear and damage. Reliable, cost-effective design to achieve prescribed component durability requires effective (i.e., accurate and efficient) structural analysis tools that account for the complex geometries, loading conditions, and forms of nonlinear material responses that characterize these components in their operating environment.

3-D INELASTIC STRUCTURAL ANALYSIS METHODS



- MATERIAL NONLINEARITIES
- GEOMETRIC NONLINEARITIES
- TEMPERATURE DEPENDENCE
- TIME DEPENDENCE

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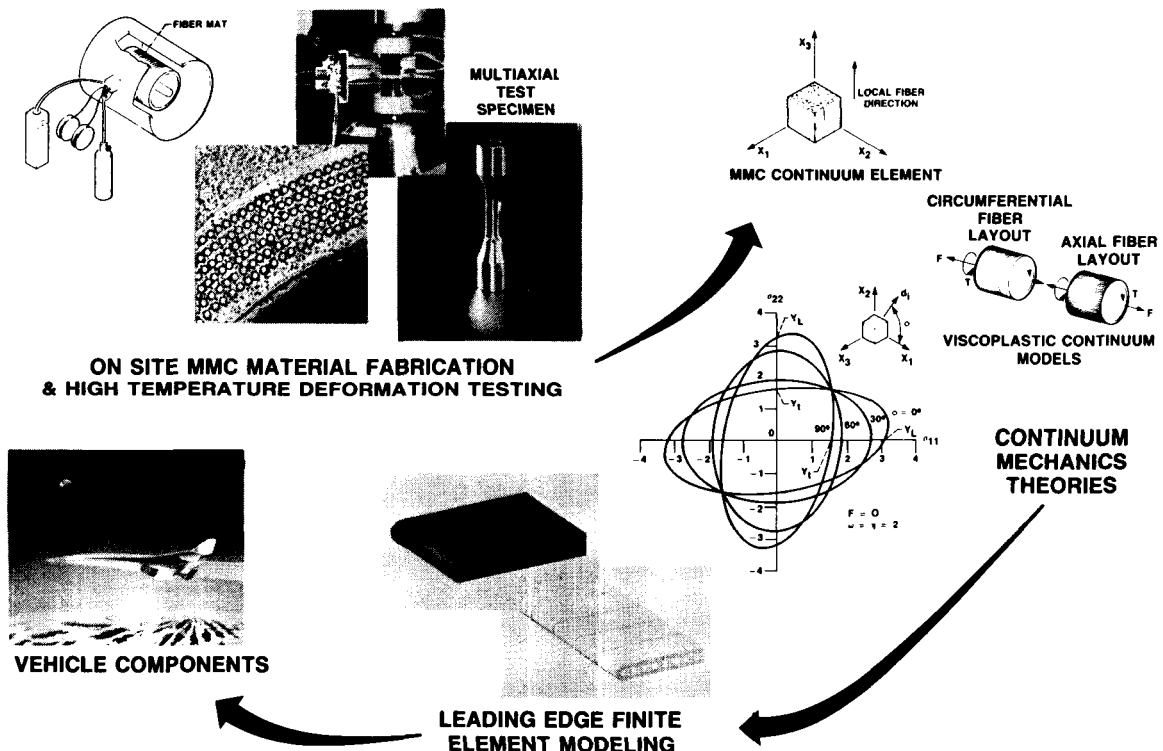
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LEWIS' UNIQUE ROLE IN METAL-MATRIX COMPOSITE TECHNOLOGY

Through a cooperative effort between the Structures and Materials Divisions, Lewis Research Center can boast of having a unique capability in metal-matrix composite (MMC) technology. The Materials Division is capable of fabricating thin-walled tubular MMC specimens which are then tested by the Structures Division under axial-torsional conditions at elevated temperatures. From these tests the necessary material functions and parameters can be determined for viscoplastic constitutive models that are also developed at Lewis. The constitutive models, in turn, are implemented into advanced structural analysis computer codes to predict the response of MMC components subjected to complex thermomechanical loading histories. These analyses provide important information to aid the engineer in making design decisions for actual aerospace vehicles.

LEWIS' UNIQUE ROLE IN METAL-MATRIX COMPOSITE (MMC) TECHNOLOGY

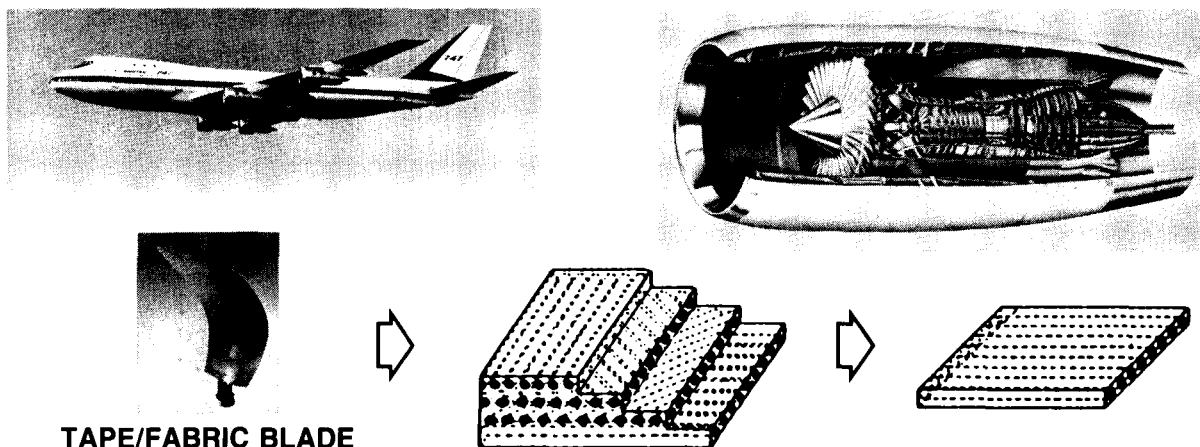


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INTEGRATED COMPOSITES ANALYZER

The numerous properties needed for composite structural design, combined with the difficulty of obtaining experimental measurements of these properties, have motivated development of the Integrated Composites Analyzer computer code. The code incorporates the appropriate composite mechanics to analyze/design multilayered fiber composites for arbitrary hygrothermal environments. Input variables to the code include material systems, volume fractions, laminate configurations, fabrication conditions, and service environment. The Integrated Composites Analyzer predicts virtually all composite hygral, thermal, and mechanical properties necessary to perform structural/stress analysis, and it has proven to be an effective tool for preliminary design of composite structures. Confidence in the predictive capabilities of the code has been established through excellent agreement with experimental data obtained for a variety of composite systems in extreme hygrothermal environments.

INTEGRATED COMPOSITES ANALYZER (ICAN)



ICAN COMPARISON

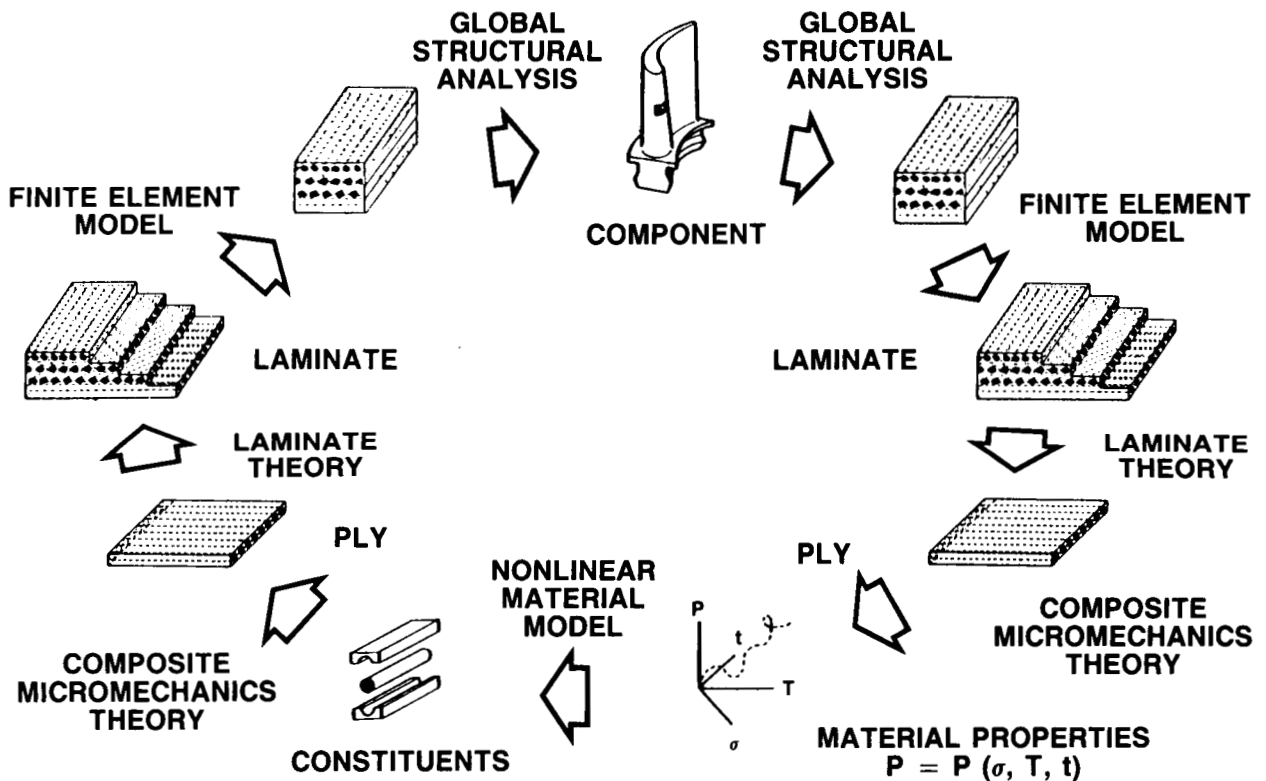
LAMINATE MATERIAL	LONGITUDINAL ELASTIC MODULUS, ksi					
	EXPERIMENTAL			ICAN PREDICTIONS		
	-300 °F	70 °F	200 °F	-300 °F	70 °F	200 °F
7781E-GLASS CLOTH	4600	4370	3970	4589	4251	4076
7576E-GLASS CLOTH	6540	6020	6050	5587	5395	5457
REPRESENTATIVE	5320	4370	4150	4440	4114	3948

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STRUCTURAL ANALYSIS FOR HIGH-TEMPERATURE COMPOSITES

The mechanical performance and structural integrity of composites are ultimately governed by the behavior of the local constituents (i.e., fiber, matrix, and interphase). This local constituent behavior is dynamic, particularly in high-temperature applications, and complex due to various nonlinearities associated with, for example, large stress/strain excursions, temperature-dependent material properties, and time-dependent effects. In the analysis/design of a composite structure, it is essential to be able to track this local behavior and relate its effects on global structural response. The integrated approach illustrated provides this capability by incorporating constituent material models/cumulative damage models, composite mechanics (micro and macro), and global structural analysis.

STRUCTURAL ANALYSIS FOR HIGH-TEMPERATURE COMPOSITES

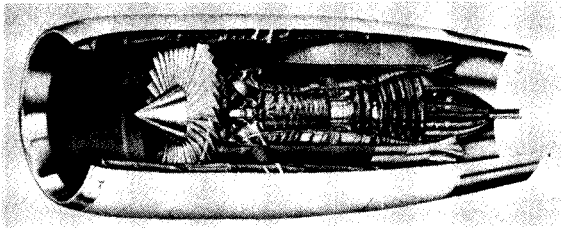


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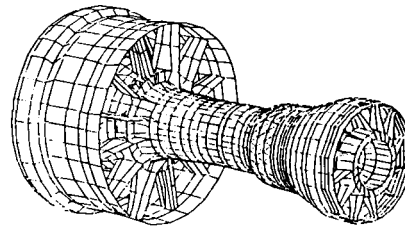
ENGINE STRUCTURES COMPUTATIONAL SIMULATOR

The Engine Structures Computational Simulator is intended to simulate the structural behavior/performance at test-stand and/or flight-mission conditions. The simulation can be for subcomponents, components (turbine blade), subassemblies (rotor sector), assemblies (rotor stage), and up to the entire engine. New design concepts, materials, mission requirements, etc., can be simulated and their potential benefits evaluated prior to detail design and testing initiation. Local or subcomponent damage effects on engine structural performance can be assessed and engine structural durability/integrity determined. With the availability of this information, the probability of unanticipated failures can be established and the safety of the engine structure ascertained.

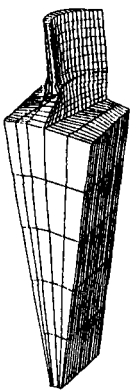
ENGINE STRUCTURES COMPUTATIONAL SIMULATOR



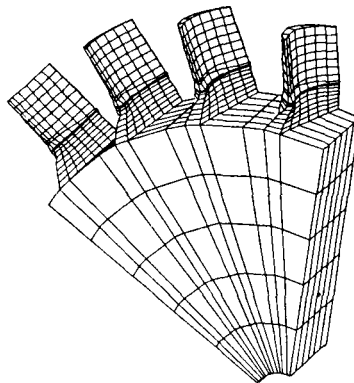
ENGINE



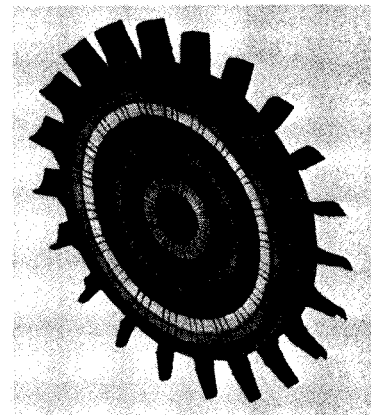
FINITE ELEMENT MODEL



BLADE



ROTOR SECTOR



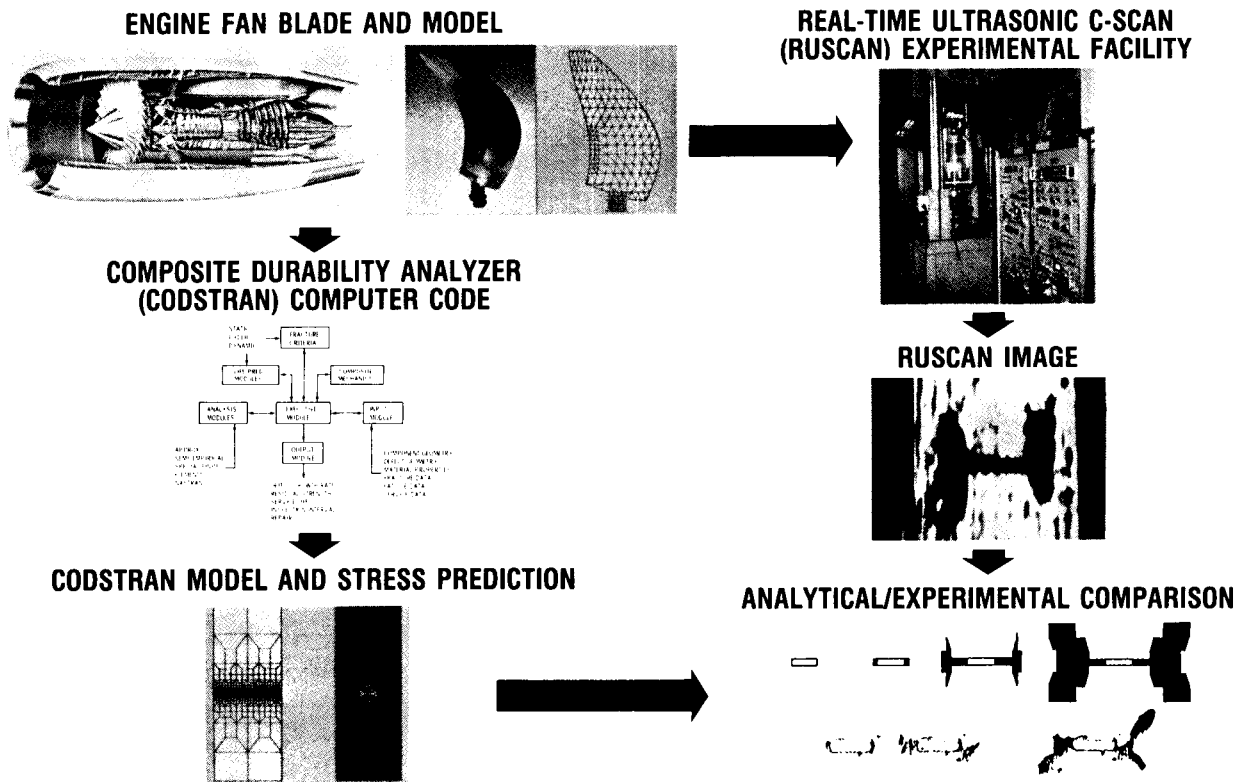
ROTOR STAGE

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INTEGRATED ANALYTICAL/EXPERIMENTAL EVALUATION OF COMPOSITE DURABILITY

In an effort to characterize durability and damage tolerance of composite structures, an integrated research program is ongoing involving analytical methods development and experimental verification. The analytical methods including composite mechanics, composite failure theories, and cumulative damage models are incorporated into the Composite Durability Structural Analyzer finite element computer code, which assesses durability in terms of defect growth/damage progression on a ply-by-ply basis through an incremental solution scheme. The companion experimental program is conducted using the unique Real-Time Ultrasonic C-Scan Facility where sequential graphic images are created from acoustic emissions taken of a specimen in real time as it is incrementally loaded to fracture. The excellent correlation achieved between the analytical predictions and experimental observations enhances confidence in the ability to analytically assess durability of composite structures.

INTEGRATED ANALYTICAL/EXPERIMENTAL EVALUATION OF COMPOSITE DURABILITY



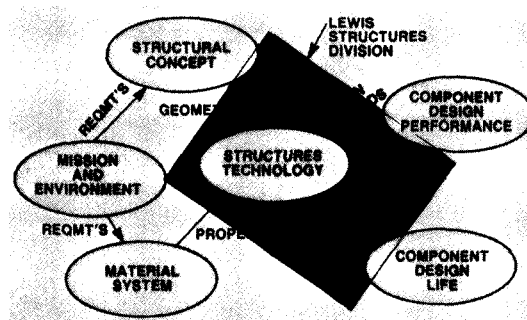
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PROBABILISTIC STRUCTURAL ANALYSIS/DESIGN METHODOLOGY

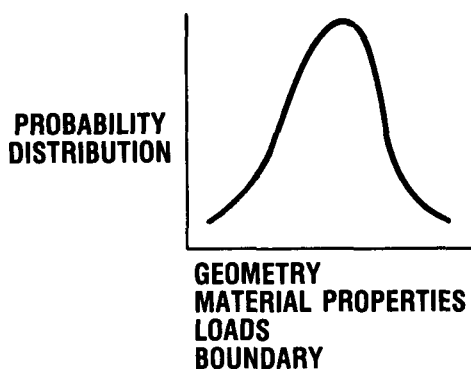
The ingredients to a structural design - i.e., geometry, material properties, boundary conditions, and loads - are "known" only with some uncertainty. Although "risk" necessarily accompanies this uncertainty, an assessment of the degree of risk associated with a design is usually not determined. Rather, the traditional approach is to rely on deterministic design methodology and incorporate some sort of "safety factor" in an attempt to simply avoid any risk. Reducing risk in a design increases safety and reliability but at the same time increases cost. In the interest of both safety and economy, it is desirable to quantify the level of risk in a design, and probabilistic methodology provides the means to accomplish this.

PROBABILISTIC STRUCTURAL ANALYSIS/DESIGN METHODOLOGY

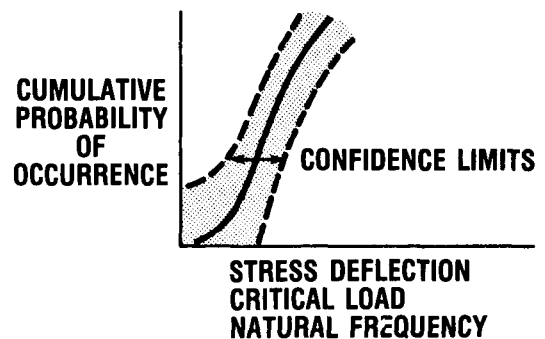
DESIGN PROCESS



"REAL WORLD" UNCERTAINTY



"REAL WORLD" STRUCTURAL RESPONSE



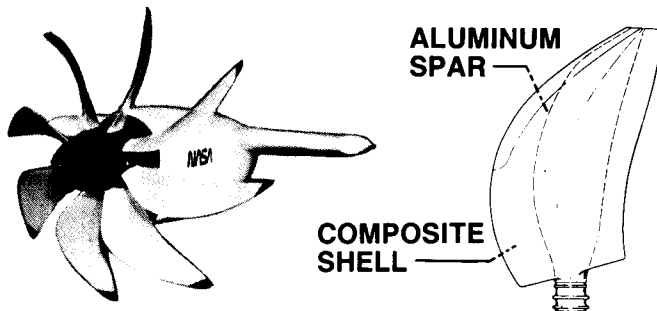
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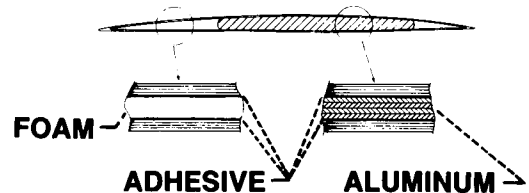
STRUCTURAL TAILORING OF ADVANCED TURBOPROP BLADES

The traditional approach to propeller design would be to satisfy requirements on aerodynamic performance and structural integrity independently through numerous manual design iterations. This process, often conducted by different designers or even groups of designers, is time consuming, cumbersome, and subjective. As a result, the process is usually carried out only to the point where a satisfactory design, but not likely the "best" design, is achieved. The Structural Tailoring of Advanced Turboprops computer code was developed to streamline, automate, and formalize the turboprop design process by incorporating multidisciplinary analysis methodology (aerodynamic, acoustic, and structural) together with numerical optimization techniques into a computationally effective design system. The system has demonstrated its utility in successful optimizations of large-scale, advanced propfan designs to achieve reductions of several percent in aircraft direct operating cost.

STRUCTURAL TAILORING OF ADVANCED TURBOPROPS (STAT)



BLADE INTERNAL STRUCTURE



TURBOPROP STAGE AND PROPELLER

MULTIDISCIPLINARY ANALYSIS MODULES

- ADS OPTIMIZER
- BLADE MODEL GENERATION
- AERODYNAMIC ANALYSIS
- ACOUSTIC ANALYSIS
- STRESS AND VIBRATIONS ANALYSIS
- FLUTTER ANALYSIS
- 1 P FORCED REPOSE

TYPICAL ANALYSIS RESULTS

	<u>INITIAL</u>	<u>FINAL</u>
EFFICIENCY, %	82.86	83.17
NEAR-FIELD NOISE, DB	143.8	137.3
WEIGHT, LB	41.1	41.2
DOC	-.853	-4.201

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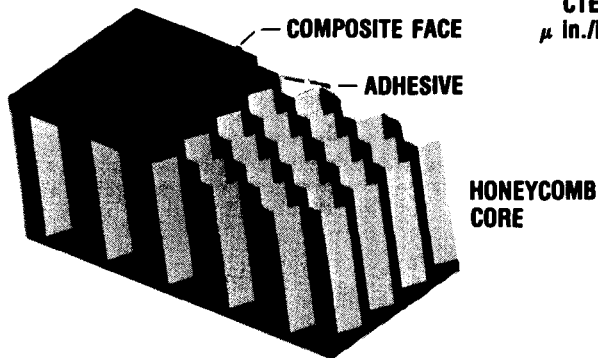
COMPOSITE SANDWICH STRUCTURAL SIMULATION FOR SATELLITE ANTENNA REFLECTORS

A recent enhancement of the Integrated Composites Analyzer computer code has extended its applicability to composite sandwich configurations. The new feature was successfully demonstrated in the preliminary design of the composite antenna reflector structure for the Advanced Communications Technology Satellite. In this application, parametric studies were conducted to determine acceptable face sheet and honeycomb core configurations necessary to provide a thermal distortion-free structure in a simulated space environment. The simplified, approximate methodology developed to model sandwich composite structures has been verified using detailed 3-D finite element analysis.

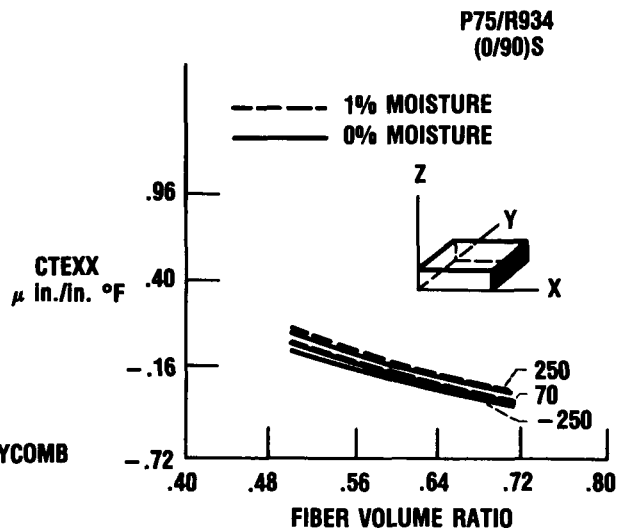
COMPOSITE SANDWICH STRUCTURAL SIMULATION FOR ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE ANTENNA REFLECTORS



**ACTS ADVANCED COMMUNICATION
TECHNOLOGY SATELLITE**



**COMPUTER-GENERATED MODEL OF THE
STRUCTURE USED FOR THE ANALYSIS**



**COEFFICIENT OF THERMAL EXPANSION
AS A FUNCTION OF FVR AND
HYGROTHERMAL CONDITIONS**

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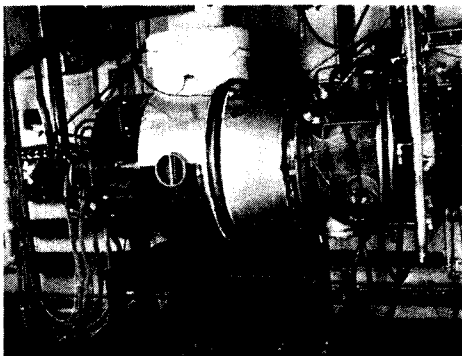
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ADVANCED COMBUSTOR LINER STRUCTURAL CONCEPT TESTING AND THERMAL/STRUCTURAL/LIFE ANALYSIS

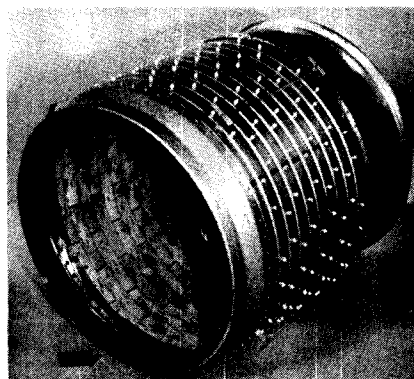
Advanced combustor liner structural concepts and materials are being tested and analyzed as part of a cooperative research program between NASA Lewis Research Center and Pratt & Whitney Aircraft. The integrated and interdisciplinary test/analysis program is conducted for advanced "floatwall" or panelled combustor liner segments. The cyclic tests, conducted in the Structural Component Response Rig, simulate the taxi, ascent, cruise, and descent temperature transients of an engine flight profile using a computer-controlled quartz lamp heating system. High-quality data bases of liner temperatures and distortions are obtained for calibration and verification of analytical models and computational tools used for predicting the structural response and life of representative liners.

INTEGRATED TEST AND THERMAL/STRUCTURAL/LIFE ANALYSIS OF AN ADVANCED COMBUSTOR STRUCTURAL CONCEPT

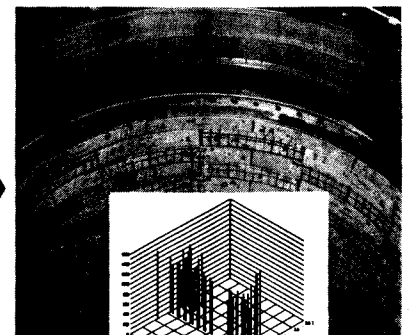
STRUCTURAL COMPONENT
RESPONSE RIG



SEGMENTED COMBUSTOR
TEST LINER

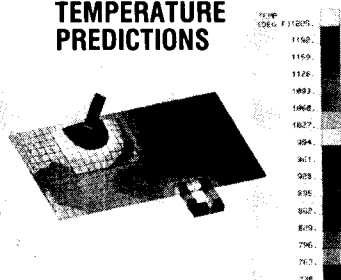


LINER TEST TO FAILURE



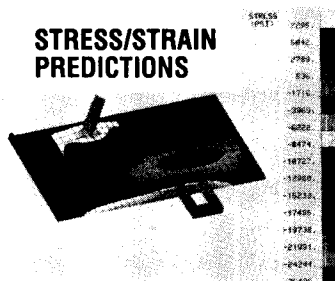
THERMAL/STRUCTURAL ANALYSIS

TEMPERATURE
PREDICTIONS

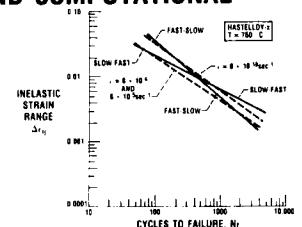


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STRESS/STRAIN
PREDICTIONS



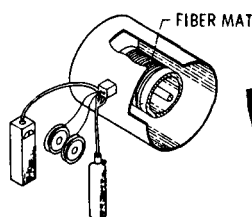
COMPARE EXPERIMENTAL DATA WITH
PREDICTIONS FOR VERIFICATION OF
MODELS AND COMPUTATIONAL
METHODS.



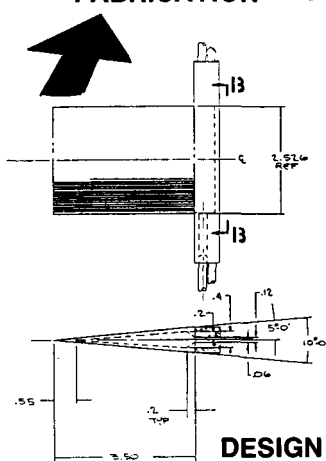
LIFE ANALYSIS

METHODOLOGY OF LEADING EDGE CONCEPT EVALUATION

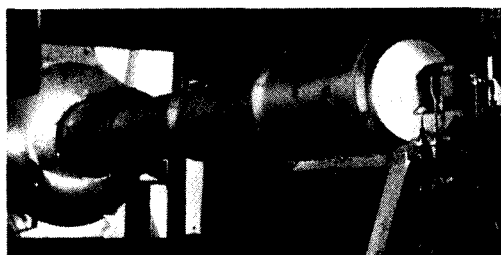
ARC SPRAY MONOTAPE FABRICATION UNIT



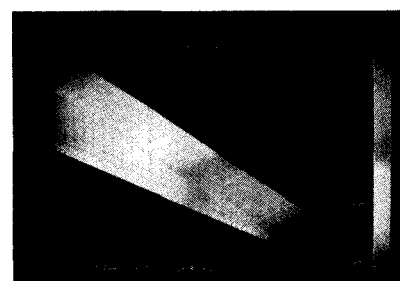
FABRICATION



DESIGN



TESTING



ANALYSIS

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